6.10 I-SECTION FLEXURAL MEMBERS

6.10.1 General

C6.10.1

Revise Paragraph 1 as follows:

This article addresses general topics that apply to all types of steel I-sections in either straight bridges, horizontally curved bridges, or bridges containing both straight and curved segments. For the application of the provisions of Article 6.10, bridges containing both straight and curved segments are to be treated as horizontally curved bridges since the effects of curvature on the support reactions and girder deflections, as well as the effects of flange bending, usually extended beyond the curved segments. Note that kinked (chorded) girders exhibit the same actions as curved girders, except that the effect of the noncollinearity of the flanges is concentrated at the kinks. Continuous kinked (chorded) girders should be treated as horizontally curved girders with respect to these Specifications. Simply supported straight (chorded) girders in horizontally curved bridges should be treated as straight skewed girders. Straight bridges are intended to mean bridges containing only straight girders or segments. Horizontally curved bridges are intended to mean bridges containing only horizontally curved girders or segments.

The five bullet items in this article indicate the overarching organization of the subsequent provisions for the design of straight I-section flexural members. Each of the sub-articles throughout Article 6.10 are written such that they are largely self-contained, thus minimizing the need for reference to multiple articles to address any one of the essential design considerations. For the strength limit state, Article 6.10.6 directs the Engineer to the subsequent Articles 6.10.7 through 6.10.12, and optionally for sections in straight I-girder only to Appendices A and B, for the appropriate design requirements based on the type of I-section. The specific provisions of these Articles and Appendices are discussed in the corresponding Articles of the Commentary.

Add the following after the second paragraph:

For horizontally curved bridges, in addition to the potential sources of flange lateral bending discussed in the preceding paragraph, flange lateral bending effects due to curvature must always be considered at all limit states and also during construction.

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6.10.11.2 Bearing Stiffeners

6.10.11.2.1 General

Revise Paragraph 4 as follows:

Each stiffener shall be either finish (mill or grind) ~~milled~~ to bear plus a fillet weld against the flange through which it receives its load or attached to that flange by a full penetration groove weld.

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6.13 CONNECTIONS AND SPLICES

6.13.1 General

Revise the first paragraph as follows:

Except as specified otherwise, connections and splices for main members shall be designed at the strength limit state for not less than ~~the larger of:~~

- ~~The average of the flexural moment-induced stress, shear, or axial force due to the factored loadings at the point of splice or connection and the factored flexural, shear, or axial resistance of the member or element at the same point,~~

~~75~~ **100** percent of the factored flexural, shear, or axial resistance of the member or element.

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6.13.6 Splices

6.13.6.1 Bolted Splices

6.13.6.1.4 Flexural Members

6.13.6.1.4b Web Splices

Revise the first and second paragraphs as follows:

Web splice plates and their connections shall be designed for shear, the moment due to the eccentricity of the shear at the point of splice and the portion of the flexural moment assumed to be resisted by the web at the point of splice. For all single box sections, and for multiple box sections in bridges not satisfying the requirements of Article 6.11.2.3 or with box flanges that are not fully effective according to the provisions of Article 6.11.1.1, including horizontally curved bridges, the shear shall be taken as the sum of the flexural and St. Venant torsional shears in the web subjected to additive shears. For boxes with inclined webs, the web splice shall be designed for the component of the vertical shear in the plane of the web.

As a minimum, at the strength limit state, the design shear, V_{uw}, shall be taken as ~~follows:~~ the factored shear resistance of the smaller web at the point of splice, $\phi v V n$.

~~If $V_u < 0.5\phi_v V_n$, then;~~

$$\cancel{V_{uw} = 1.5 V_u} \qquad \cancel{(6.13.6.1.4b\text{-}1)}$$

~~otherwise:~~

$$\cancel{V_{uw} = \frac{(V_u + \phi_v V_n)}{2}} \qquad \cancel{(6.13.6.1.4b\text{-}2)}$$

where:

ϕ_v = resistance factor for shear specified in Article 6.5.4.2

~~V_u = shear due to the factored loading at the point of splice (kip)~~

V_n = nominal shear resistance determined as specified in Articles 6.10.9.2 and 6.10.9.3 for unstiffened and stiffened webs, respectively (kip)

C6.13.6.1.4b

Delete the first paragraph.

~~Eqs. 1 and 2 provide a more consistent design shear to be used for designing web splice plates and their connections at the strength limit state than that given in past editions of the Standard Specifications and the First Edition of the LRFD Specifications. Eq. 1 arbitrarily limits the increase in the shear at the point of splice to 50 percent of the shear due to the factored loading, V_u, where V_u is less than 50 percent of the factored shear resistance, $V_r = \phi_v V_n$, at the point of splice. The increase in the shear is limited to 50 percent of V_u because the possibilities for V_u to change from its calculated value are less than for moment; large unintended shifts in the shear at the splice are unlikely. In addition, the maximum shear is usually not concurrent with the maximum moment at the splice. Thus, the use of a lower value of the design shear in regions where the applied shear is low is deemed reasonable. A lower value of the design shear is also more reasonable for rolled beams, which have significantly higher values of factored shear resistance. For cases where V_u is greater than 50 percent of V_r, the design shear is determined from Eq. 2 as the average of V_u and V_r. For checking slip of the bolted connections, the design shear is simply taken as the shear at the point of splice under Load Combination Service II defined in Table 3.4.1-1.~~

Revise Equations (C6.13.6.1.4b-1) and (C6.13.6.1.4b-2), third to sixth paragraphs as follows:

$$\cancel{M_{uw} = \frac{t_w D^2}{12}\left|R_h F_{cf} - R_{cf} f_{ncf}\right|} \qquad \cancel{(C6.13.6.1.4b\text{-}1)}$$

$$\cancel{H_{uw} = \frac{t_w D}{2}\left(R_h F_{cf} + R_{cf} f_{ncf}\right)} \qquad \cancel{(C6.13.6.1.4b\text{-}2)}$$

For compact sections:

$$M_{uw} = \phi_f \frac{t_w F_{yw}}{4}\left(D^2 - 4 y_o^2\right) \qquad (C6.13.6.1.4b\text{-}1a)$$

$$H_{uw} = \phi_f \left(2\ t_w y_o F_{yw}\right) \qquad (C6.13.6.1.4b\text{-}2a)$$

For noncompact sections:

If the controlling flange is in compression:

$$M_{uw} = \phi_f \frac{t_w D^2}{12} F_{nc}\left(1 + \frac{S_{xc}}{S_{xt}}\right) \quad \text{(C6.13.6.1.4b-1b)}$$

$$H_{uw} = \phi_f \frac{t_w D}{2} F_{nc}\left(\frac{S_{xc}}{S_{xt}} - 1\right) \quad \text{(C6.13.6.1.4b-2b)}$$

If the controlling flange is in tension:

$$M_{uw} = \phi_f \frac{t_w D^2}{12} R_h F_{yt}\left(1 + \frac{S_{xt}}{S_{xc}}\right) \quad \text{(C6.13.6.1.4b-1c)}$$

$$H_{uw} = \phi_f \frac{t_w D}{2} R_h F_{yt}\left(1 - \frac{S_{xt}}{S_{xc}}\right) \quad \text{(C6.13.6.1.4b-2c)}$$

where:

t_w = web thickness (in.)

D = web depth (in.)

R_h = hybrid factor specified in Article 6.10.1.10.1. ~~For hybrid sections in which F_{cf} does not exceed the specified minimum yield strength of the web, the hybrid factor shall be taken as 1.0~~

~~F_{cf} = design stress for the controlling flange at the point of splice specified in Article 6.13.6.1.4c; positive for tension, negative for compression (ksi)~~

~~R_{cf} = the absolute value of the ratio of F_{cf} to the maximum flexural stress, f_{cf}, due to the factored loads at the midthickness of the controlling flange at the point of splice, as defined in Article 6.13.6.1.4c~~

~~f_{ncf} = flexural stress due to the factored loads at the midthickness of the noncontrolling flange at the point of splice concurrent with f_{cf}; positive for tension, negative for compression (ksi)~~

F_{nc} = nominal flexural resistance of the compression flange at the point of splice as specified in Article 6.10.8.2 (ksi)

F_{yt} = specified minimum yield strength of the tension flange at the point of splice (ksi)

F_{yw} = specified minimum yield strength of the web at the point of splice (ksi)

S_{xc} = elastic section modulus about the major axis of the section to the compression flange at the point of splice ($in.^3$)

S_{xt} = elastic section modulus about the major axis of the section to the tension flange at the point of splice ($in.^3$)

y_o = distance from the mid-depth of the web to the plastic neutral axis (in.)

ϕ_f = resistance factor for flexure specified in Article 6.5.4.2

In Eqs. C1 and C2, it is suggested that M_{uw} and H_{uw} be computed by conservatively using the flexural resistance ~~stresses at the midthickness~~ of the flanges. ~~By utilizing the stresses at the midthickness of the flanges, the same stress values can be used for the design of both the web and flange splices, which simplifies the calculations.~~ As an alternate, however, the stresses at the inner fibers of the flanges can be used. In either case, the stresses are to be computed considering the flexural resistance of the controlling flange at the strength limit state. ~~the application of the moments due to the appropriate factored loadings to the respective cross sections supporting those loadings. In Eqs. C1 and C2, the concurrent flexural stress at the midthickness of the noncontrolling flange is factored up in the same proportion as the flexural stress in the controlling flange in order to satisfy the general design requirements of Article 6.13.1.~~ The controlling and noncontrolling flanges are defined in Article C6.13.6.1.4c.

~~The stresses in Eqs. C1 and C2 are to be taken as signed quantities. For convenience, absolute value signs are applied to the resulting difference of the stresses in Eq. C1. In actuality, t~~The sign of M_{uw} corresponds to the sign of the flexural moment for the loading condition under consideration. H_{uw} ~~in Eq. C2~~ is taken as a signed quantity; positive for tension, negative for compression. For sections where the neutral axis is located at the middepth of the web, H_{uw} will equal zero. For all other sections, M_{uw} and H_{uw} applied together will yield a combined stress distribution equivalent to the unsymmetrical stress distribution in the web.

Eqs. C1d and C2d can ~~also~~ be used to compute values of M_{uw} and H_{uw} to be used when checking for slip of the web bolts. ~~However, the following substitutions must first be made in both equations:~~

- ~~replace F_{cf} with the maximum flexural stress, f_s, due to Load Combination Service II at the midthickness of the flange under consideration for the smaller section at the point of splice,~~
- ~~replace f_{ncf} with the flexural stress, f_{os}, due to Load Combination Service II at the midthickness of the other flange at the point of splice concurrent with f_s in the flange under consideration, and~~
- ~~set the factors R_h and R_{cf} equal to 1.0. It is not necessary to determine a controlling and noncontrolling flange when checking for slip. The same sign convention applies to the stresses.~~

$$M_{uw} = \frac{t_w D^2}{12}\left|f_s - f_{os}\right| \qquad \text{(C6.13.6.1.4b-1d)}$$

$$H_{uw} = \frac{t_w D}{2}\left(f_s + f_{os}\right) \qquad \text{(C6.13.6.1.4b-2d)}$$

where:

f_s = maximum flexural stress due to Load Combination Service II at the extreme fiber of the flange under consideration for the smaller section at the point of splice (positive for tension and negative for compression) (ksi)

f_{os} = flexural stress due to Load Combination Service II at the extreme fiber of the other flange at the point of splice with f_s in the flange under consideration (positive for tension and negative for compression) (ksi)

In Eqs. C1d and C2d, it is suggested that M_{uw} and H_{uw} be computed by conservatively using the stresses at the extreme fiber of the flanges. As an alternate, however, the stresses at the midthickness of the flanges or the inner fibers of the flanges can be used. In either case, the stresses are to be computed considering the application of the moments due to the appropriate factored loadings to the respective cross-sections supporting those loadings.

~~R_{cf} = the absolute value of the ratio of F_{cf} to the maximum flexural stress, f_{cf}, due to the factored loads at the midthickness of the controlling flange at the point of splice, as defined in Article 6.13.6.1.4c~~

~~f_{ncf} = flexural stress due to the factored loads at the midthickness of the noncontrolling flange at the point of splice concurrent with f_{cf}; positive for tension, negative for compression (ksi)~~

6.13.6.1.4c Flange Splices

Revise Eq. (6.13.6.1.4c-1) as follows:

$$\cancel{F_{cf} = \frac{\left(\left|\frac{f_{cf}}{R_h}\right| + \alpha\phi_f F_{yf}\right)}{2} \geq 0.75\alpha\phi_f F_{yf}}$$

$$\underline{F_{cf} = \alpha\,\phi_f\,F_{yf}}$$

(6.13.6.1.4c-1)

in which:

A_e = effective area of the flange (in.^{2}). For compression flanges, A_e shall be taken as the gross area of the flange. For tension flanges, A_e shall be taken as:

$$A_e = \left(\frac{\phi_u F_u}{\phi_y F_{yt}}\right) A_n \leq A_g \qquad (6.13.6.1.4c\text{-}2)$$

where:

~~f_{cf} = design maximum flexural stress due to the factored loads at the midthickness of the controlling flange at the point of splice (ksi)~~

~~R_h = hybrid factor specified in Article 6.10.1.10.1. For hybrid sections in which F_{cf} does not exceed the specified minimum yield strength of the web, the hybrid factor shall be taken as 1.0~~

α = 1.0, except that a lower value equal to (F_n/F_{yf}) may be used for flanges where F_n is less than F_{yf}

ϕ_f = resistance factor for flexure specified in Article 6.5.4.2

F_n = nominal flexural resistance of the flange (ksi)

F_{yf} = specified minimum yield strength of the flange (ksi)

ϕ_u = resistance factor for fracture of tension members as specified in Article 6.5.4.2

ϕ_y = resistance factor for yielding of tension members as specified in Article 6.5.4.2

A_n = net area of the tension flange determined as specified in Article 6.8.3 (in.^{2})

C6.13.6.1.4c

Revise third paragraph as follows:

The controlling flange is defined as either the top or bottom flange for the smaller section at the point of splice, whichever flange has the maximum ratio of the elastic flexural stress at its <u>extreme fiber</u> ~~midthickness~~ due to the factored loads for the loading condition under investigation to its factored flexural resistance. The other flange is termed the noncontrolling flange. In areas of stress reversal, the splice must be checked independently for both positive and negative flexure. For composite sections in positive flexure, the controlling flange is typically the bottom flange. For sections in negative flexure, either flange may qualify as the controlling flange.

Revise the fifth paragraph as follows:

Eq. 3 defines a design stress for the noncontrolling flange at the strength limit state. In Eq. 3, the flexural stress at ~~the midthickness of~~ the noncontrolling flange, <u>is</u> concurrent with the stress in the controlling flange~~, is factored up in the same proportion as the flexural stress in the controlling flange in order to satisfy the general design requirements of Article 6.13.1~~. However, as a minimum, the ~~factored up~~ stress must be equal to or greater than $0.75\alpha\,\phi_f F_{yf}$.

Delete the seven paragraph as follows:

~~Since flanges of hybrid girders are allowed to reach F_{yf}, the applied flexural stress at the midthickness of the flange in Eqs. 1, 3 and 5 is divided by the hybrid factor, R_h, instead of reducing F_{yf} by R_h. In actuality, yielding in the web results in an increase in the applied flange stress. When the flange design stress is less than or equal to the specified minimum yield strength of the web, R_h is taken equal to 1.0 since there is theoretically no yielding in the web. The load shedding factor, R_b, is not included in these equations since the presence of the web splice plates precludes the possibility of local web buckling.~~

Revise the 10th paragraph as follows:

A_g = gross area of the tension flange (in.^{2})
F_u = specified minimum tensile strength of the tension flange determined as specified in Table 6.4.1-1 (ksi)
F_{yt} = specified minimum yield strength of the tension flange (ksi)

Splice plates and their connections on the noncontrolling flange at the strength limit state shall be proportioned to provide a minimum resistance taken as the design stress, F_{ncf}, times the smaller effective flange area, A_e, on either side of the splice, where F_{ncf} is defined as:

Revise Eq. (6.13.6.1.4c-3) as follows:

$$\cancel{F_{ncf} = R_{cf}\left|\frac{f_{ncf}}{R_h}\right| \geq 0.75\alpha\phi_f F_{yf}}$$

$$F_{ncf} = \frac{F_{cf} S_{xcf}}{S_{xncf}} \geq 0.75\,\alpha\,\phi_f F_{yf}$$

(6.13.6.1.4c-3)

where:

S_{xcf} = elastic section modulus about the major axis of the section to the controlling flange at the point of splice (in.^{3})

S_{xncf} = elastic section modulus about the major axis of the section to the noncontrolling flange at the point of splice (in.^{3})

~~R_{cf} = the absolute value of the ratio of F_{cf} to f_{cf} for the controlling flange~~

~~f_{ncf} = flexural stress due to the factored loads at the midthickness of the noncontrolling flange at the point of splice concurrent with f_{cf} (ksi)~~

~~R_h = hybrid factor specified in Article 6.10.1.10.1. For hybrid sections in which f_{cf} does not exceed the specified minimum yield strength of the web, the hybrid factor shall be taken as 1.0~~

At the strength limit state, the design force in splice plates subjected to tension shall not exceed the factored resistance in tension specified in Article 6.13.5.2. The design force in splice plates subjected to compression shall not exceed the factored resistance, R_r, in compression taken as:

Revise Eq. (6.13.6.1.4c-5) as follows:

For the box sections cited in this article, longitudinal warping stresses due to cross-section distortion can be significant under construction and service conditions and must therefore be considered when checking the connections of bolted flange splices for slip and for fatigue. The warping stresses in these cases can typically be ignored in checking the top-flange splices once the flange is continuously braced. The warping stresses can also be ignored when checking splices in both the top and bottom flanges at the strength limit state. For these sections, St. Venant torsional shear must also be considered in the design of box-flange bolted splices at all limit states. St. Venant torsional shears are typically neglected in top flanges of tub sections once the flanges are continuously braced. The bolts for box-flange splices may be designed for the effects of the torsional shear using the traditional elastic vector method that is typically applied in the design of web splices. Depending on the limit state under investigation, the shear on the flange bolt group is assumed caused by either the flange force due to the factored loads, or by the appropriate flange design force, as applicable. The moment on the bolt group is taken as the moment resulting from the eccentricity of the St. Venant torsional shear due to the factored loads, assumed applied at the centerline of the splice. At the strength limit state, a design torsional shear due to factored loads should be used~~, which can be taken as the torsional shear due to the factored loads multiplied by the factor, R_{cf}, from Eq. 3~~. The box-flange splice plates in these cases should also be designed at the strength limit state for the combined effects of the calculated design shear and design moment acting on the bolt group.

Revise the 11th paragraph as follows:

In cases where flange lateral bending is deemed significant, the effects of the lateral bending must be considered in the design of the bolted splices for discretely braced top flanges of tub sections or discretely braced flanges of I-sections. The traditional elastic vector method may also be used in these cases to account for the effects of flange lateral bending on the design of the splice bolts. The shear on the flange bolt group is assumed caused by the flange force, calculated as described in the preceding

$$F_s = \frac{f_s}{R_h} \qquad (6.13.6.1.4c\text{-}5)$$

where:

f_s = maximum flexural stress due to Load Combination Service II at the extreme fiber ~~midthickness~~ of the flange under consideration for the smaller section at the point of splice (ksi)

R_h = hybrid factor specified in Article 6.10.1.10.1. For hybrid sections in which f_s in the flange with the larger stress does not exceed the specified minimum yield strength of the web, the hybrid factor shall be taken as 1.0.

paragraph. The flange force is calculated without consideration of the flange lateral bending. The moment on the bolt group is taken as the flange lateral bending moment due to the factored loads. At the strength limit state, a design lateral bending moment due to the factored loads should be used~~, which can be taken as the lateral bending moment due to the factored loads multiplied by the factor, R_{cf}, from Eq. 3~~. Splice plates subject to flange lateral bending should also be designed at the strength limit state for the combined effects of the calculated design shear and design moment acting on the bolt group. Lateral flange bending can be ignored in the design of top flange splices once the flange is continuously braced.